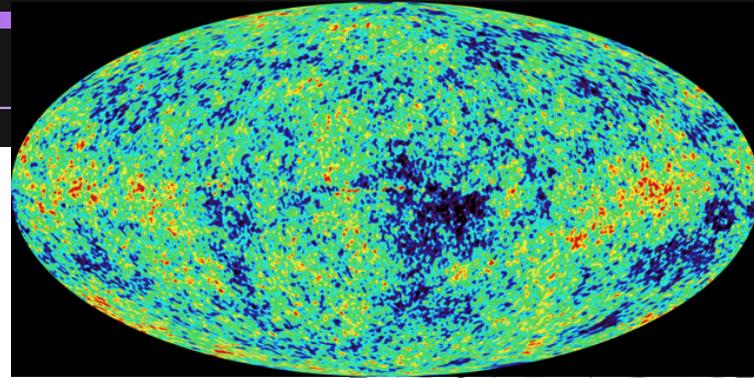




# Elementary Connections

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89 Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	--	--	--		114 --		116 --		118 --
		58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu		
		90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr		

# The Big Bang



1																	2														
H																	He														
3	4															9	10														
Li	Be															Ne															
11	12															7	18														
Na	Mg															Al	Si	P	S	Cl	Ar										
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36														
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr														
37	38	39	40					46	47	48	49	50	51	52	53	54															
Rb	Sr	Y	Zr	Nb					Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe														
55	56	57	72					78	79	80	81	82	83	84	85	86															
Cs	Ba	La	Hf	Ta					Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn														
87	88	89	104	105					110	111	112			114			118														
Fr	Ra	Ac	Rf	Db					--	--	--			--			--														
																		58	59	60	61	62	63	64	65	66	67	68	69	70	71
																		Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
																		90	91	92	93	94	95	96	97	98	99	100	101	102	103
																		Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr



# *The Big Bang Cosmology*

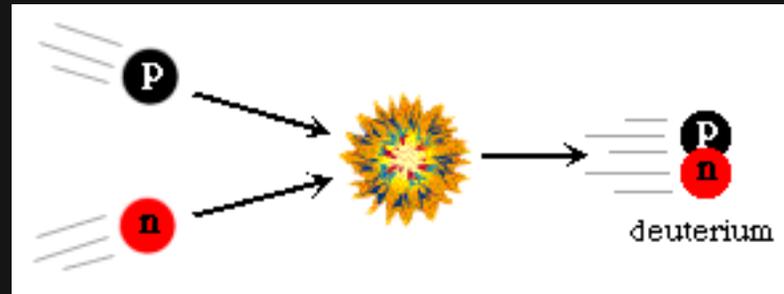
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- The expansion of the universe began at a finite time in the past, in a state of enormous density, pressure and temperature.
- “Big Bang” is a highly successful family of theories with no obvious competitor.
  - Explains what we see, and has made several successful predictions.

# Big Bang Nucleosynthesis

Within first three minutes, Hydrogen & Helium formed.

- At  $t = 1$  s,  $T = 10,000,000,000$  K: soup of particles: photons, electrons, positrons, protons, neutrons. Particles created & destroyed.
- At  $t = 3$  min,  $T = 1,000,000,000$  K:  $p + n \Rightarrow D$



- $D + D \Rightarrow He$

# Your Cosmic Connection to the Elements?

National Aeronautics and Space Administration

## What is Your Cosmic Connection to the Elements?

**Small Stars**

**Large Stars**

**Supernovae**

**Cosmic Rays**

**Big Bang**

Hydrogen  
Helium

Carbon  
Nitrogen

Sulfur  
Calcium  
Oxygen  
Silicon

Gold  
Iron  
Titanium

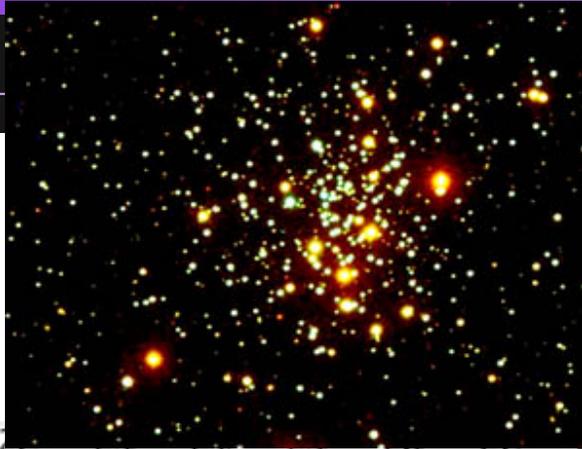
Lithium

Happy Birthday!

Imagine the Universe  
<http://imagine.gsfc.nasa.gov/>  
<http://www.nasa.gov/>

1																	2
H																	He
3	4											6	7	8	9	10	
Li	Be											C	N	O	F	Ne	
11	12											14	15	16	17	18	
Na	Mg											Si	P	S	Cl	Ar	
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Cobalt	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
Rb	Sr	Y	Zr	Nb	Mo	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe	
55	56	57	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
87	88	89	106	107	108	109	110	111	112	113	114	115	116	117	118	--	--
Fr	Ra	Ac	Rf	Db	Sg	Bh	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb
58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	76	77	78	79
90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107
Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr	108	109	110	111

# Small Stars



1 H																	2 He				
3 Li	4 Be															5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg															13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr				
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe				
55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn				
87 Fr	88 Ra	89 Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 --	111 --	112 --	113 --	114 --	115 --	116 --	117 --	118 --				
		58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu						
		90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr						



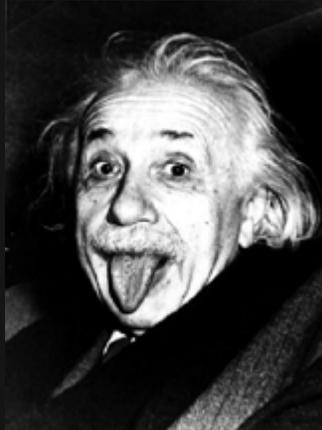
# *Small Stars: Fusion of light elements*

Fusion: (at 15 million degrees !)

$4\ (^1\text{H}) \Rightarrow\ ^4\text{He} + 2\ e^+ + 2\ \text{neutrinos} + \text{energy}$

Where does the energy come from ?

Mass of four  $^1\text{H} >$  Mass of one  $^4\text{He}$



$$E = mc^2$$

# *Small Stars to Red Giants*

---

After Hydrogen is exhausted in core,  
Energy released from nuclear fusion no longer counter-acts  
inward force of gravity.

- Core collapses,
  - Kinetic energy of collapse converted into heat.
  - This heat expands the outer layers.
- Meanwhile, as core collapses,
  - Increasing Temperature and Pressure ...

# *Beginning of Heavier Elements*

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At 100 million degrees Celsius, Helium fuses:



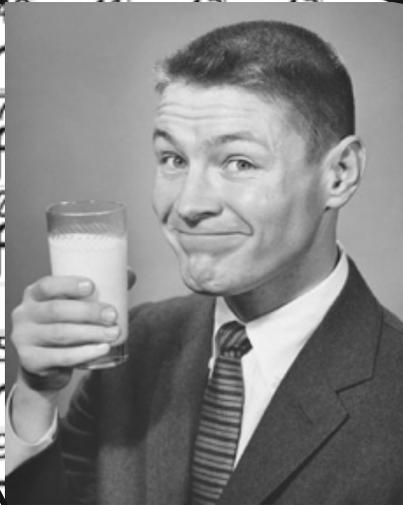
After Helium exhausted, small star not large enough to attain temperatures necessary to fuse Carbon.



# Large Stars



1																	2										
H																	He										
3	4													5	6	7	8	9	10								
Li	Be													B	C	N	O	F	Ne								
11	12													13	14	15	16	17	18								
Na	Mg													Al	Si	P	S	Cl	Ar								
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36										
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr										
37	38	39													45	46	47	48	49	50	51	52	53	54			
Rb	Sr	Y	Zr													Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe		
55	56	57													77	78	79	80	81	82			85	86			
Cs	Ba	La	Hf													Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn		
87	88	89	10													109	110	111	112			114			118		
Fr	Ra	Ac	Rf													Mt	--	--	--			--			--		
			58	59													64	65	66	67	68	69			72	73	74
			Ce	Pr													Gd	Tb	Dy	Ho	Er	Tm	Yb			Lu	
			90	91													96	97	98	99	100	101	102			106	
			Th	Pa													Cm	Bk	Cf	Es	Fm	Md	No	Lr			



# *Heavy Elements from Large Stars*

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Large stars also fuse Hydrogen into Helium, and Helium into Carbon.

But their larger masses lead to higher temperatures, which allow fusion of Carbon into Magnesium, etc.

# Element Formation through Fusion

Light Elements → Heavy Elements

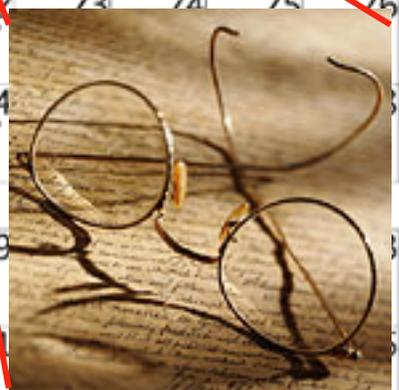
H																	He	
Li	Be											B	C	N	O	F	Ne	
Na	Mg											Al	Si	P	S	Cl	Ar	
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr	
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe	
Cs	Ba		Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn	
Fr	Ra		Rf	Db	Sg	Bh	Hs	Mt	Uun	Uuu	Uub							
		La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu		
		Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr		



# Supernova



1																	2						
H																	He						
3	4													7	8	9	10						
Li	Be													B	C	N	O	F	Ne				
11	12													13	14	15	16	17	18				
Na	Mg													Al	Si	P	S	Cl	Ar				
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36						
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr						
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54						
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe						
55	56	57	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86						
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn						
87	88	89	104													109	110	111	112	114	116	118	
Fr	Ra	Ac	Rf													Mt	--	--	--	--	--	--	
		58	59													64	65	66	67	68	69	70	71
		Ce	Pr													Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
		90	91													96	97	98	99	100	101	102	103
		Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr								



# Supernova

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Fusion of Iron takes energy, rather than releases energy.

So fusion stops at Iron.

Energy released from nuclear fusion no longer counter-acts inward force of gravity.

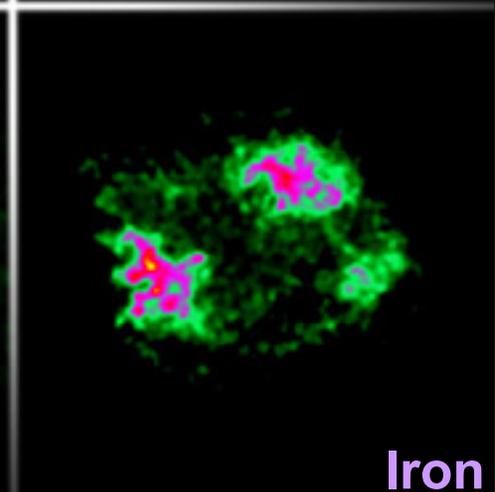
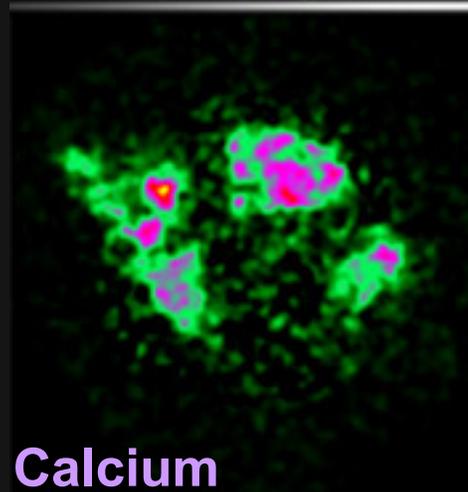
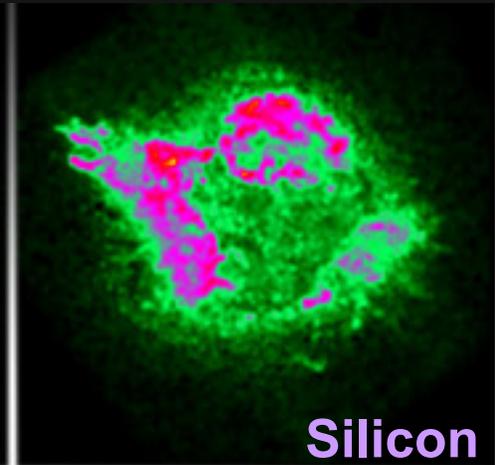
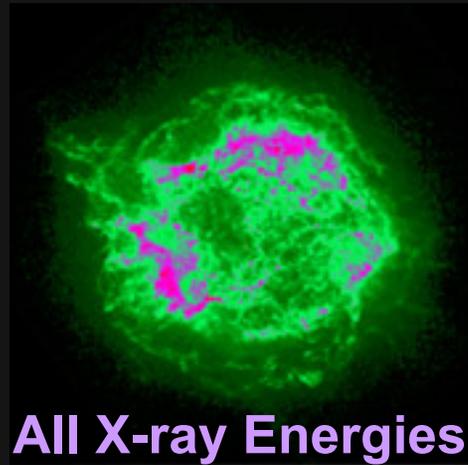
But now there is nothing to stop gravity.

Massive star ends its life in supernova explosion.

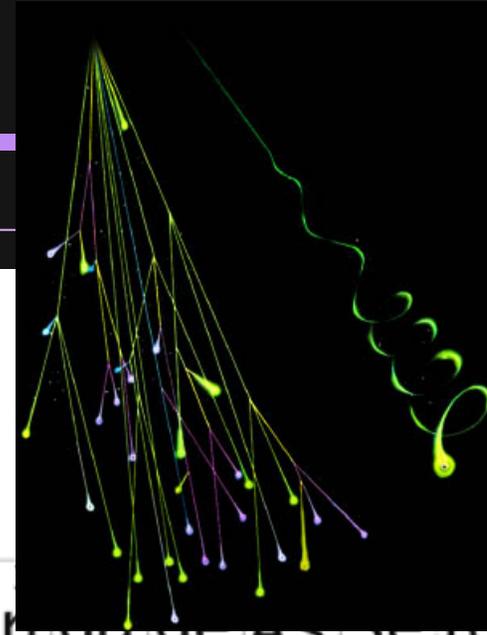
# Supernova

Explosive power of a supernova:

- Disperses elements created in large stars.
- Creates new elements, especially those heavier than Iron.



# Cosmic Rays



# Cosmic Rays

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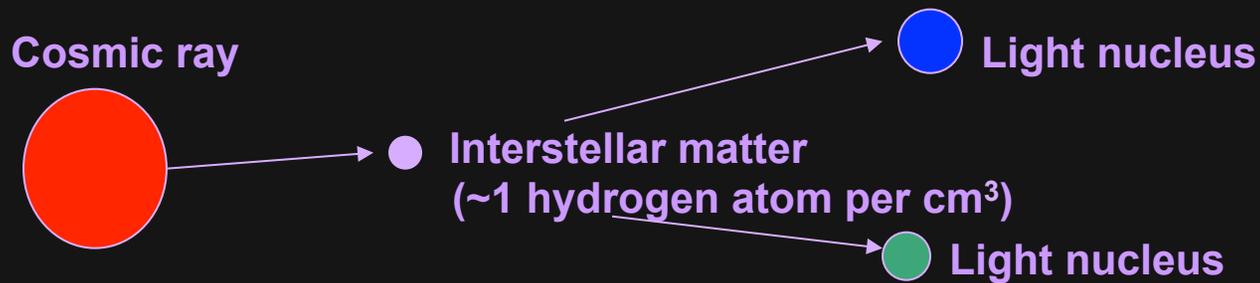
Lithium, Beryllium, and Boron are difficult to produce in stars.

(L, Be, and B are formed in the fusion chains, but they are unstable at high temperatures, and tend to break up into residues of He, which are very stable).

So what is the origin of these rare elements?

=> Collisions of Cosmic Rays with Hydrogen & Helium in interstellar space.

# Cosmic Rays Collisions with ISM



Lithium, beryllium, and boron and sub-iron enhancements attributed to nuclear fragmentation of carbon, nitrogen, oxygen, and iron with interstellar matter (primarily hydrogen and helium).



# Cosmic Elements

1 H																	2 He														
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne														
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar														
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr														
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																		90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

White - Big Bang

Pink - Cosmic Rays

Yellow - Small Stars

Green - Large Stars

Blue - Supernovae

# Your Cosmic Connection to the Elements?

National Aeronautics and Space Administration

## What is Your Cosmic Connection to the Elements?

**Small Stars**

- Carbon
- Nitrogen

**Large Stars**

- Sulfur
- Calcium
- Oxygen
- Silicon

**Supernovae**

- Gold
- Iron
- Titanium

**Cosmic Rays**

- Lithium

**Big Bang**

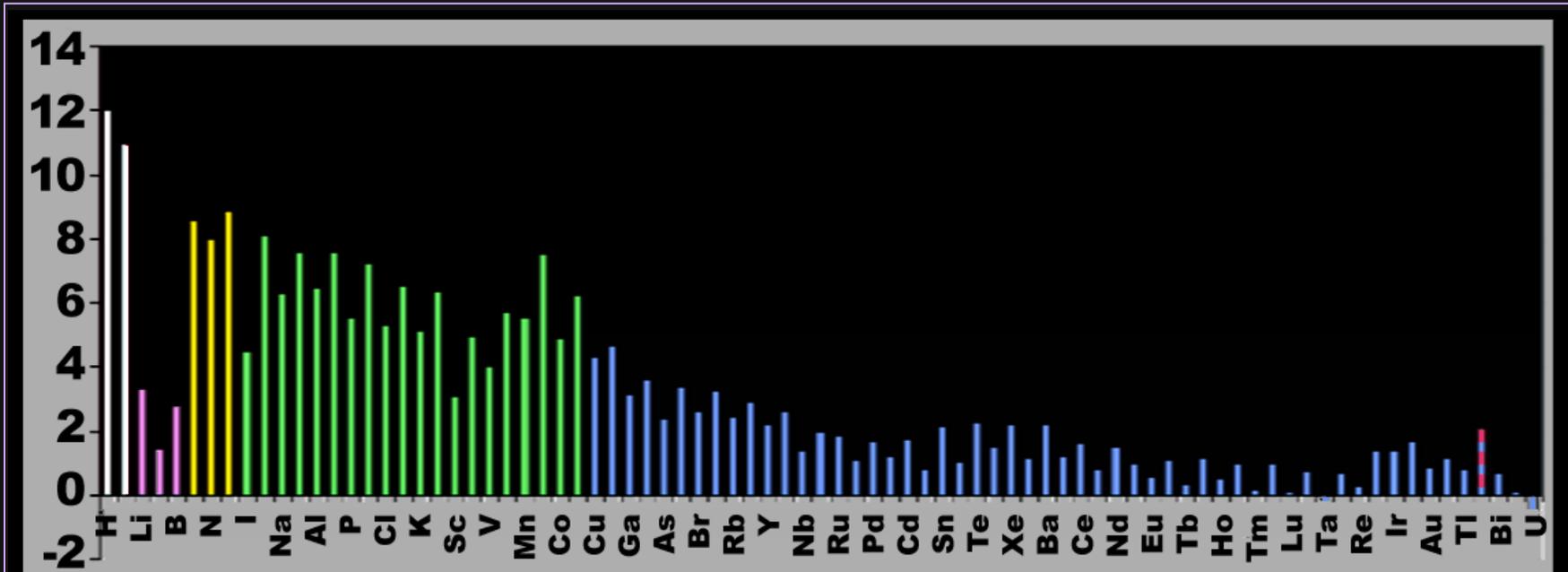
- Hydrogen
- Helium

**Periodic Table Elements:**

1																	2														
H																	He														
3	4															6	7	8	9	10											
Li	Be															C	N	O	F	Ne											
11	12															14	15	16	17	18											
Na	Mg															Si	P	S	Cl	Ar											
19	20	21	22											25	26	27	28	29	30	31	32	33	34	35	36						
K	Ca	Sc	Ti	V											Mn	Fe	Co	Ni	Cu	Zn	Ge	As	Se	Br	Kr						
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Rb	Sr	Y	Zr	Nb											Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe						
55	56	57	72	73											75	76	77	78	79	80	81	82	83	84	85	86					
Cs	Ba	La	Hf	Ta											Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn								
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Fr	Ra	Ac	Rf	Db											Rg	Cf	Es	Fm	Md	No	Lr										
																		58	59	60	61	62	63	64	65	66	67	68	69	70	
																		Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
																		90	91	92	93	94	95	96	97	98	99	100	101	102	103
																		Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

Imagine the Universe  
<http://imagine.gsfc.nasa.gov/>  
<http://www.nasa.gov/>

# Composition of the Universe



Actually, this is just the solar system.

Composition varies from place to place in universe, and between different objects.

# *“What’s Out There?”*

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(Developed by Stacie Kreitman, Falls Church, VA)

A classroom activity that demonstrates the different elemental compositions of different objects in the universe.

- Demonstrates how we estimate the abundances.

# *Top 10 Elements in the Human Body*

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	Element	by # atoms
10.	Magnesium (Mg)	0.03%
9.	Chlorine (Cl)	0.04%
8.	Sodium (Na)	0.06%
7.	Sulfur (S)	0.06%
6.	Phosphorous (P)	0.20%
5.	Calcium (Ca)	0.24%
4.	Nitrogen (N)	1.48%
3.	Carbon (C)	9.99%
2.	Oxygen (O)	26.33%
1.	Hydrogen (H)	61.56%

# *Spectral Analysis*

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We can't always get a sample of a piece of the Universe.

So we depend on light !

# *Spectral Analysis*

---

Each element has a unique spectral signature:

- Determined by arrangement of electrons.
- Lines of emission or absorption arise from re-arrangement of electrons into different energy levels.



Hydrogen

# Nickel-odeon Classroom Activity

(Developed by Shirley Burris, Nova Scotia)

Spread a rainbow of color across a piano keyboard



Then, “play” an element



Hydrogen

# More Musical Elements

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Now play another element

Helium



And Another

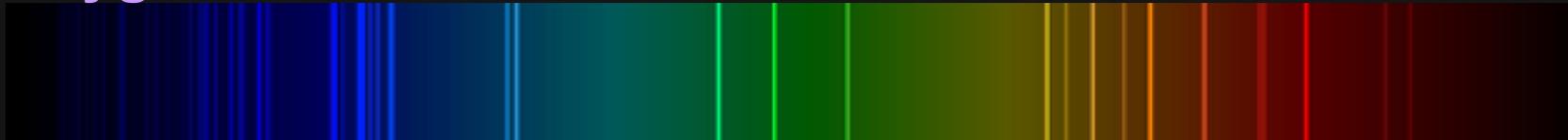
Carbon



# Getting a Handle on Water



Oxygen



Hydrogen



All together now ... Water

# Your Cosmic Connection to the Elements?

National Aeronautics and Space Administration

## What is Your Cosmic Connection to the Elements?

**Small Stars**

**Large Stars**

**Supernovae**

**Cosmic Rays**

**Big Bang**

Hydrogen  
Helium

Carbon  
Nitrogen

Sulfur  
Calcium  
Oxygen  
Silicon

Gold  
Iron  
Titanium

Lithium

Imagine the Universe  
<http://imagine.gsfc.nasa.gov/>  
<http://www.nasa.gov/>

<http://imagine.gsfc.nasa.gov/docs/teachers/elements/>

# *Cosmic Connections*

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To make an apple pie from scratch,  
you must first invent the universe.

Carl Sagan